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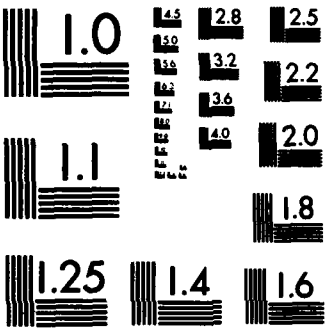

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PRINCIPLES OF SPREAD SPECTRUM SYSTEMS

ONR CONTRACT N0OO14-82-K-0328

Annual Report

September 1, 1982 - September 1, 1983

Charles L. Weber

CSI-83-09-02

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A summary of the work accomplished under ONR Contract No. N00014-82-K-0328 is presented for the year Sept. 1, 1982-Sept. 1, 1983. This is accomplished by presenting the abstracts of the papers published and those that have been accepted during this reporting period.

In addition, three students received their Ph.D. degree as a result of efforts supported and/or directed under this ONR contract. Abstracts of these dissertations are also included herein.

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PRINCIPLES OF SPREAD SPECTRUM SYSTEMS

ANNUAL REPORT

for the period

Sept. 1, 1982 to Sept. 1, 1983

Charles L. Weber

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In addition, three students received their Ph.D. degree as a result of efforts supported and/or directed under this ONR contract. The abstracts of their dissertations are also included as part of this annual report.

1. ANALYSIS AND OPTIMIZATION OF CORRELATIVE CODE-TRACKING LOOPS IN SPREAD SPECTRUM SYSTEMS

A. Polydoros and C.L. Weber

A B S T R A C T

Here we apply the renewal theory approach for analyzing aperiodic finite S-curve code-tracking loops developed by Meyr to the case of a noncoherent arbitrary offset early/late delay-loop ("noncoherent δ-LL"). The exact (renewal) approach is compared with the approximate (periodic S-curve or phase-locked loop PLL) theory, as well as with the linear theory developed herein for the aforementioned code-tracking loop Finally, loop optimization with respect to the offset δ is carried out. The results indicate that, for low SNR, the exact and approximate theories could deviate significantly while for high SNR, all three theories yield identical performance. It is also shown that the optimal δ for both low and high SNR differs from the commonly accepted choice δ=1/2.

* The above paper is published in the Proceedings of MILCOM '82, Boston, Mass.

2. OPTIMAL DETECTION CONSIDERATIONS FOR LOW PROBABILITY OF INTERCEPT

A. Polydoros & C.L. Weber

A B S T R A C T

A variety of receivers which can be used to detect the presence of a wideband (spread) signal in additive white Gaussian noise (AGWN) is explored. The optimality of these receivers is founded upon the know ɔdge (or lack thereof) of certain key signal parameters. Suboptimal receivers are suggested based upon the removal of knowledge of some of these parameters.

* The above paper is published in the Proceedings of MILCOM '82, Boston, Mass.

3. THE PERFORMANCE OF DIRECT-SEQUENCE SYSTEMS IN THE PRESENCE OF JAMMERS

C.L. Weber and G.K. Huth

A B S T R A C T

An enumeration of the types of interference pertinent to direct-sequence systems is given. The candidates are categorized as narrowband or wideband. The performance of direct-sequence 9DS) systems in the presence of a variety of types of interference is also presented. When the jammer has a choice of parameters, the optimal value is then determined.

* The above paper is published in the Proceedings of MILCOM '82, Boston, Mass.

4. MULTIPLE DWELL SERIAL SEARCH: PERFORMANCE AND APPLICATION TO DIRECT SEQUENCE CODE ACQUISITION

D.M. DiCarlo and C.L. Weber

A B S T R A C T

The technique of multiple dwell serial search is described and analyzed. The advantage of the multiple dwell procedure is that the examination interval need not be fixed, allowing incorrect cells to be quickly discarded, which in turn results in a shorter search time than is possible with a fixed dwell time procedure. This type of search scheme is particularly useful for direct sequence code acquisition in a spread spectrum communication system. An expression for the generating function is obtained from a flow graph representation of the multiple dwell technique. The generating function is used to develop expressions for the mean and variance of the search time in terms of the following parameters: the dwell times, the detection probability, the false alarm probability, and the false alarm penalty time. Coherent detector characteristics are then used to investigate the performance of the multiple dwell technique for direct sequence code acquisition. It is shown that the multiple dwell procedure can significantly reduce the expected acquisition time from that obtained with a single dwell system.

The most significant improvement is obtained by using a two-dwell system. Additional but nominal improvement is gained when more than two dwells are employed.

* The above paper is published in the IEEE Transactions on Communications, May 1983.

5. A UNIFIED APPROACH TO SERIAL SEARCH SPREAD-SPECTRUM CODE ACQUISITION PART I: GENERAL THEORY

A. Polydoros and C.L. Weber

A B S T R A C T

The purpose of this two-part paper is threefold: (1) Part I discusses the code-

acquistion problem in some depth and, (2) also provides a general extension to the approach of analyzing serial-search acquisition techniques via transform-domain flow graphs; (3) Part II illustrates the applicability of the proposed theoretical framework by evaluating a matched-filter (fast-decision rate) noncoherent acquisition receiver as an example.

The theory is formulated in a general manner which allows for significant freedom in the receiver modeling. The statistics of the acquisition time for the single-dwell [2,3] and N-dwell [5] systems are shown to be special cases of this unified approach.

* The above paper has been accepted for publication in the IEEE Transactions on Communications, and is scheduled ot appear in the near future.

6. A UNIFIED APPROACH TO SERIAL SEARCH SPREAD-SPECTRUM CODE ACQUISITION PART II: A MATCHED-FILTER RECEIVER

A. Polydoros and C.L. Weber

A B S T R A C T

The unified theory developed in part I [1] is employed here in the analysis of a noncoherent, matched-filter (fast-decision rate) code acquisition receiver in a direct-sequence spread-spectrum-system. The results illustrate the dramatic dependence of the mean acquisition time on system parameters, such as the predetection signal-to-noise ratio (SNR), the decision threshold settings and the ratio of the decision rate to the code rate.

* The above paper has been accepted for publication in the IEEE Transactions on Communications, and is scheduled to appear in the near future.

7. GENERALIZED SERIAL SEARCH CODE ACQUISITION: THE EQUIVALENT CIRCULAR STATE-DIAGRAM APPROACH

A. Polydoros

A B S T R A C T

A simple circular state-diagram method has been recently proposed [2] for the modeling, analysis and optimization of straight serial search code acquisition in spread spectrum systems. Herein, the approach is generalized to arbitrary serial strategies, such as the Z-search, expanding window search etc. The basis idea is the construction of equivalent circular state-diagrams, wherefrom the transform-domain description of the stochastic acquisition process is derived. The method circumvents any complicated time-domain combinatorial arguments, is readily systematized and includes recent results as special cases.

* The above paper has been submitted to the IEEE Transactions on Communications.

8. ANALYSIS AND OPTIMIZATION OF CORRELATIVE CODE-TRACKING LOOPS IN SPREAD SPECTRUM SYSTEMS

A. Polydoros and C.L. Weber

A B S T R A C T

Here we apply the renewal theory approach for analyzing aperiodic finite S-curve code-tracking loops developed by Meyr (ref. 1) to a case of a noncoherent arbitrary offset early/late delay-locked loop (noncoherent δ-DLL"). The exact (renewal) approach is compared with the approximate (periodic extension) approach of suing the periodic S-curve or phase-locked loop (PLL) theory, as well as with the linear theory developed herein for the aforementioned code-tracking loop. Finally, a loop optimization with respect to the offset δ is carried out. The results indicate that, for low SNR, the exact and approximate theories could deviate significantly while, for high SNR, all three theories yield identical performance. It is also shown that the optimal δ for both low and high SNR differs from the commonly accepted choice of δ=1/2.

* The above paper has been accepted for publication by the IEEE Transactions on Communications, and is presently under final revision.

9. GENERALIZED SERIAL SEARCH CODE ACQUISITION: THE EQUIVALENT CIRCULAR STATE-DIAGRAM APPROACH

A. Polydoros

A B S T R A C T

A simple circular state-diagram method has been recently proposed [2] for the modeling, analysis and optimization of straight serial search code acquisition in spread spectrum systems. Herein, the approach is generalized to arbitrary serial strategies, such as the Z-search, expanding window search, etc. The basic idea is the construction of equivalent circular state-diagram, wherefrom the transform-domain description of the stochastic acquisition process is derived. The method circumvents any complicated time-domain combinatorial arguments, is readily systematized and includes recent results as special cases.

* The above paper is published in the Proceedings of MILCOM 1983, Washington D.C.

10. WORST-CASE JAMMING FOR FREQUENCY-HOPPING CODE ACQUISITION

P. Pawlowski and A. Polydoros

A B S T R A C T

This paper is concerned with the description, analysis and optimization of an FH spread spectrum code acquisition system in the presence of partial-band noise interference plus thermal noise. The system employs matched-filter detection with hard

per-channel decisions and a multiple-test verification logic. The results show that a robust jamming strategy is wideband, independently of the jammer-to-signal power ratio, and that performance is fairly sensitive to the limiter threshold setting.

* The above paper is published in the Proceedings of MILCOM 1983, Washington, D.C.

11. ADVANCES IN MULTIPLE DWELL AND SEQUENTIAL SERIAL SYNCHRONIZATION OF PSEUDONOISE SIGNALS

Yu-Teh Su

* A Dissertation presented to the Communication Sciences Institute, University of Southern California, Los Angeles, California, April 1983)

A B S T R A C T

The process of PN signal acquisition is decomponsed by repeated applications of the theorem on total probability, into semi-Markov process. The method of generating function is then utilized to obtain statistical information on the acquisition process, notably the mean and variance of acquisition time. The exploitation of the semi-Markov nature of the acquisition process with a simple probability theorem in fact unifies the seemingly different approaches of Braun, Weinberg and Polydoros & Weber.

The main part of this thesis is devoted to the other phase of the PN acquisition problem, namely, the design of an optimal detector. Our criterion of optimality is to achieve the minimum mean acquisition time under the worst possible time offset condition. Two major families of tests - the multiple dwell tests (MDT) and the sequential tests (ST), or, the variable dwell time tests (VDT) - are proposed, their behaviors analyzed, performances evaluated and compared. It is found that the performance of the MDT improves as N, the number of dwells, increases so long as N is not too large. The ST, if properly designed are capable of outperforming the MDT. Both MDT and ST are discussed in two distinct environments, namely, the coherent code synchronization (CCS) case and the noncoherent code synchronization (NCS) case.

All the numerical results are confined to the situation when no apriori information are available and a so-called straight line search strategy is adapted. But our analyses can be readily applied to obtain performances in other environments once the corresponding generating functions are found.

12. SEMI-MARKOV ANALYSIS FOR ACQUISITION SYSTEMS, WITH APPLICATION TO SPREAD SPECTRUM COMMUNICATION ACQUISITION PROBLEM

Thomas E. Carter

* A Dissertation presented to the Communication Sciences Institute, University of Southern California, Los Angeles, California, April 1983.

A B S T R A C T

Many acquisition systems in the field of Electrical Engineering share a common underlying structure, and thus may be studied using the same generic model. A new approach, which utilizes Semi-Markov processes, is presented for analyzing the performance of any such system. Specifically, an algorithm is developed for finding the moment generating function of the probability density for the acquisition time. Techniques for deriving this probability density from the generating function are discussed and expressions for the mean and variance of the acquisition time are derived.

The primary motivation for this study is the analysis of the acquisition problem associated with spread spectrum communication systems. A unified approach is provided for both variable and fixed dwell time systems, as well as for virtually all spread spectrum search strategies currently in use. Several such search strategies are specifically analyzed, including the State Estimation, the discrete N-dwell, and various Serial Search acquisition systems. The statistics associated with a number of Direct Sequence spread spectrum detection algorithms are also derived. Both coherent and noncoherent receivers are considered.

The Serial Search, variable dwell time, sequential test for a Direct Sequence spread spectrum signal acquisition system using a coherent receiver is analyzed in detail. Exact expressions for the mean and variance of the acquisition time of this system are derived. Several unexpected results are discussed. Chief among these is that optimization of the system parameters to minimize the mean acquisition time produces a very small probability of detection per individual sweep of the uncertainty region with a corresponding short mean time to test an incorrect phase hypothesis.

13. DESIGN OF PN CODE TRACKING LOOPS OPERATING IN AN INDEPENDENT W.S.S. INTERFERENCE ENVIRONMENT

Raimundo Sampaio-Neto

* A Dissertation presented to the Communication Sciences Institute, University of Southern California, Los Angeles, California. September 1983.

A B S T R A C T

In situations where the processing gain of a spread spectrum system is not enough to overcome the problems created by a very small input signal-to-noise ratio, some extra protection has to be included in the receiver. When the interference is narrowband compared to the RF bandwidth of the system, a viable extra protection can be provided by the presence of a notch filter preceding the despreading of the spread spectrum signal.

Since successful despreading requires accurate code synchronization (acquisition and tracking), is of great concern to the efficiency of the synchronization circuits when operating in very low SNR environments.

Our work focused on the tracking portion of the circuit. Both baseband and noncoherent code tracking were considered:

* (i) For the baseband (coherent) code tracking, we considered a general configuration for a tracking loop using correlation techniques. The received signal - corrupted by an independent wide sense stationary interference - is filtered and cross-correlated with a filtered version of the receiver generated replica of the transmitted code signal. The result of this cross-correlation is then used to control the phase of the receiver's code generator. The filter pair satisfies a specified relation in order to guarantee the generation of an odd tracking function.

Using this configuration and the minimization of the RMS timing error induced by the interfering signal, as the criterion, we obtained the optimum filter pair. We also showed that causal filter design is possible.

* (ii) For RF (non-coherent) code tracking, we considered a configuration where the received waveform is filtered and simultaeously cross-correlated with signals obtained through two independent filterings of the receiver's replica of the code signal. The result of these cross-correlations are then multiplied to generate the feedback phase control signal. Using the same basic approach and criterion mentioned in the baseband case, we were able to obtainthe optimum transfer function for the filters and again we showed that causal filter design is possible.

TRAVEL UNDER THE ONR CONTRACT

1. WHO:	Charles L. Weber
WHERE:	Bedford, Mass.
WHY:	To attend MILCOM '82, give presentations and follow up on sessions organized.
WHEN:	October 14-October 20, 1982.
2. WHO:	Andreas Polydoros
WHERE:	Bedford, Mas.
WHY:	To attend MILCOM'82, give a presentation and chair a session.
WHEN:	October 14-October 20, 1982.
3. WHO:	Charles L. Weber
WHERE:	Galveston, Texas
WHEN:	November 8 and November 9, 1982
WHY:	To attend NTC '82 and organize a panel discussion.
4. WHO:	Andreas Polydoros
WHERE:	Wickenburg, Arizona
WHEN:	May 1-4, 1983
WHY:	To attend USC-ARO Workshop on Research Trends in Military Communications.
5. WHO:	Charles L. Weber
WHERE:	Hot Springs, Virginia
WHEN:	June 13-15, 1983
WHY:	To attend IEEE Workshop on "Multi-User Information Theory and Systems" and give a presentation.

Ph.D. STUDENTS

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